LER Limitations of Thin EUV Resists: Mechanistic Study into Root Causes

Brian Cardineau,[1] William Earley,[1] Avyaya Jayanthinarasimhan,[1]
Tomohisa Fujisawa,[2] Ken Maruyama,[3] Makato Shimizu,[2]
Shalini Sharma,[3] Karen Petrillo,[4] and Robert Brainard[1]

1. College of Nanoscale Science and Engineering, University at Albany
2. JSR Corporation
3. JSR Micro Inc.
4. SEMATECH, Albany, NY

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I. Introduction
II. PAG Segregation
III. Glass-Transition Temperature
IV. Summary and Future Directions

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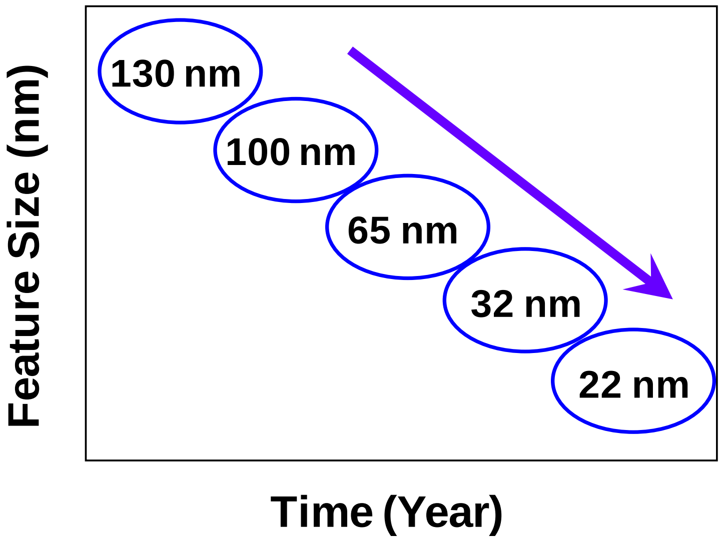
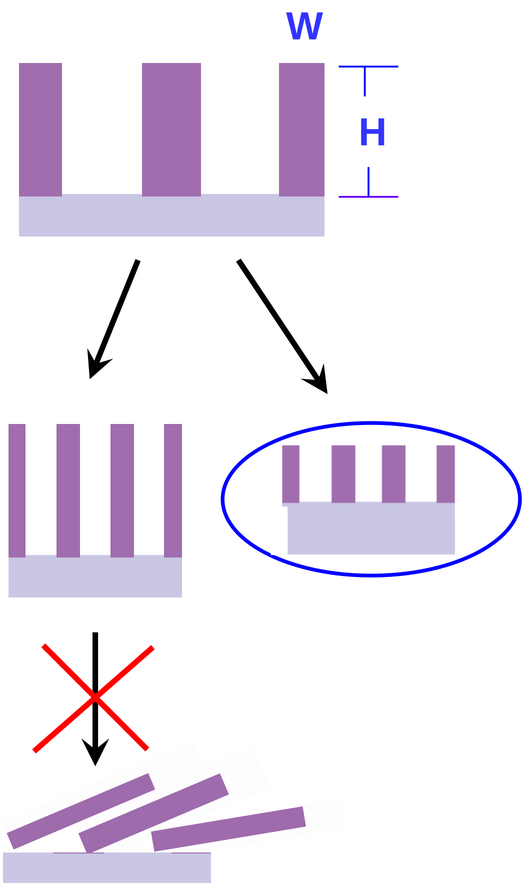
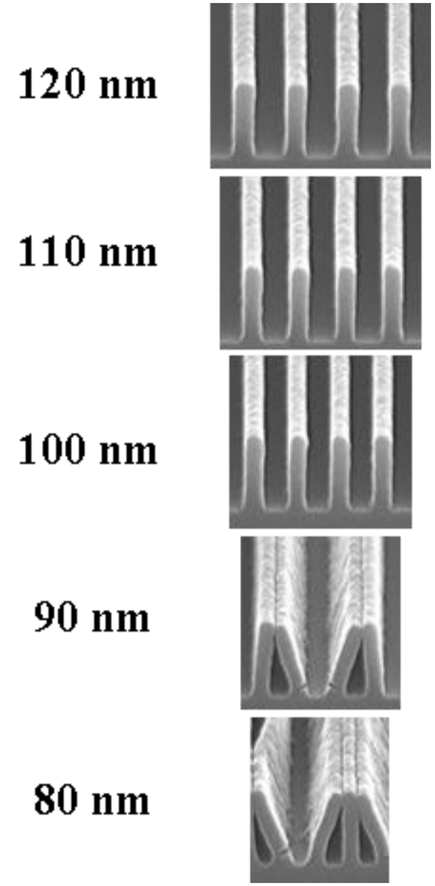
I. Introduction

As Resolution Improves, Resist Thickness must Decrease to Prevent Line Collapse







2011 LER Limits of Resist Thin Films:

LER Degrades with Decreasing Film Thickness

← Film Thickness →

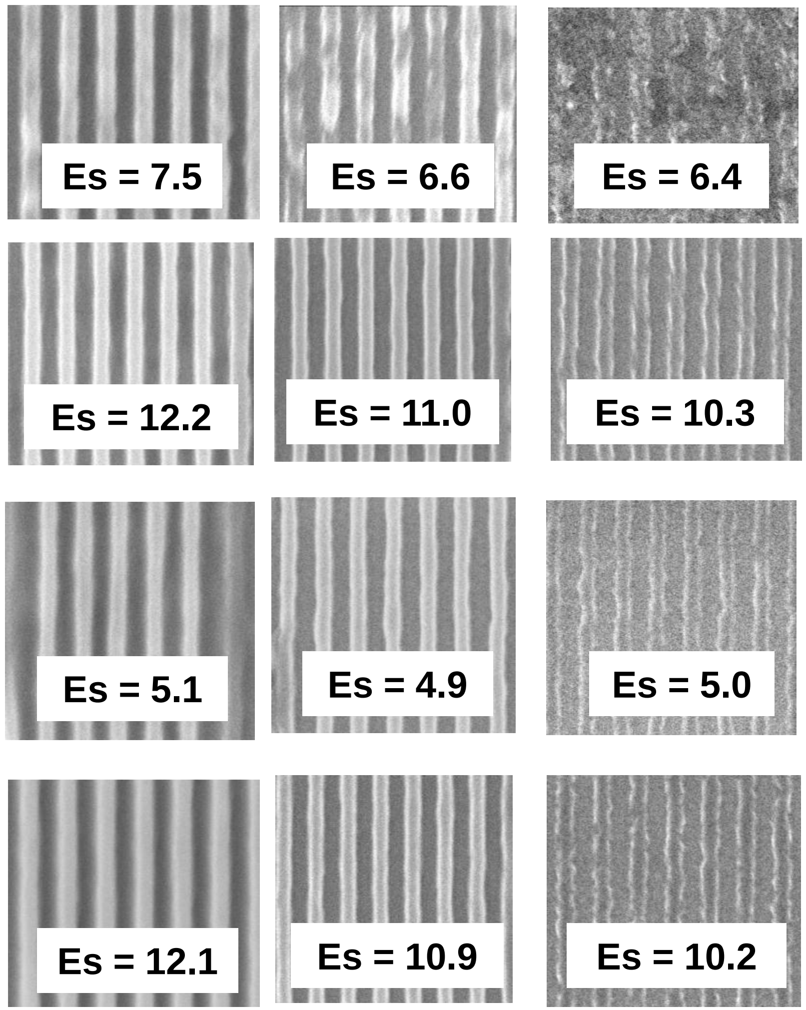
120 nm | 60 nm | 30 nm

CNSE: OS1

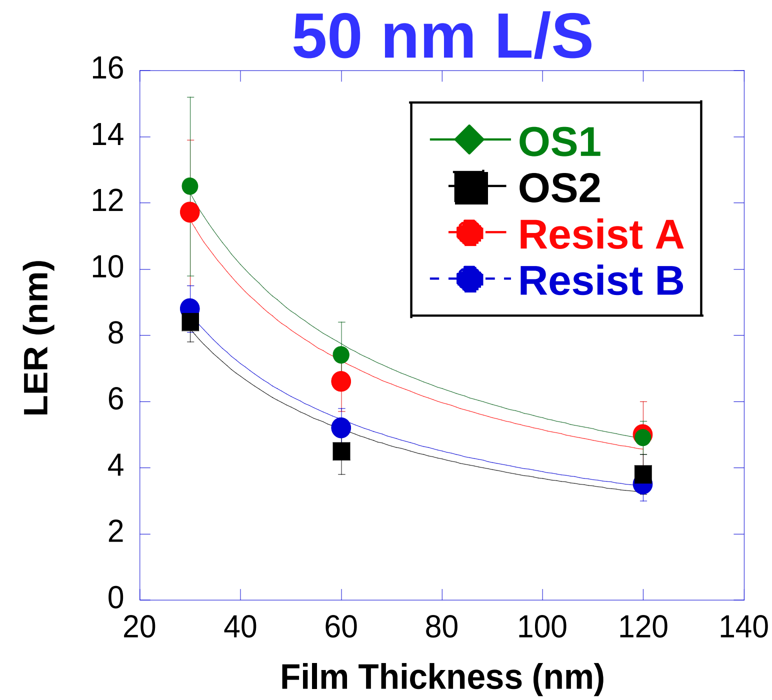
CNSE: OS2

Resist A

Resist B



Four resists from three sources all show same problem.



Es = Esize (mJ/cm^2)

LER Limits of Resist Thin Films

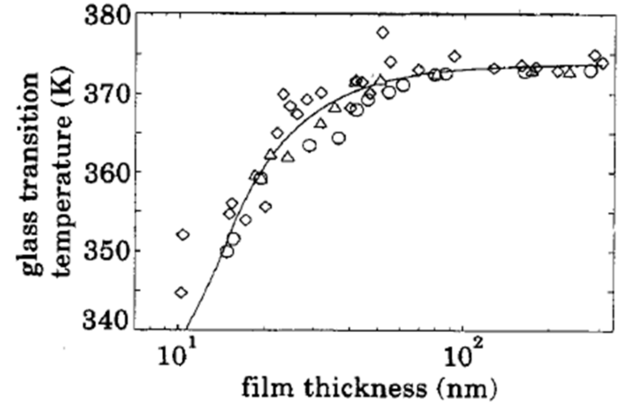
Determine the root cause of the degradation of LER vs. thickness in EUV resists by studying this phenomenon as a function of resist:

- **PAG Segregation - Today**
- **Glass Transition Temperature (Tg) - Today**
- **Substrate Interaction – SPIE**
- **Optical Density – SPIE**

Model for LER vs. Film Thickness

Keddie Model for Tg as a function of film thickness:

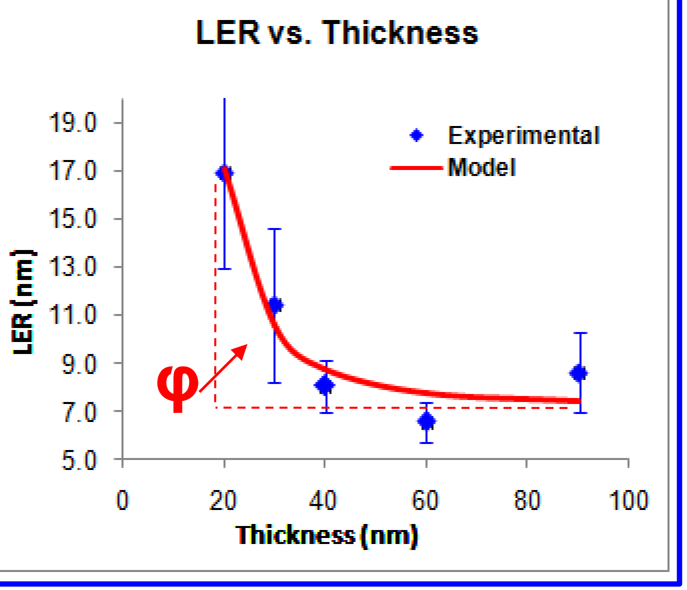
$$T_g(d) = T_{g\infty}\left[1 - \left(\frac{A}{d}\right)^{\delta}\right]$$



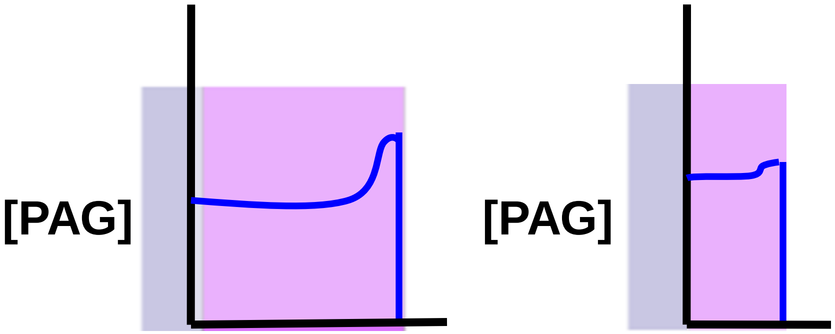
CNSE Model for LER as a function of film thickness:

$$LER(d) = LER_{\infty}\left[1 + \left(\frac{A'}{d}\right)^{\delta'}\right]$$

$T_g(\infty)$ = Bulk Tg
A' = Thickness Dependence
δ' = Exponential
φ = Area under LER curve
(Larger φ → Worse LER thickness dependence)



II. PAG Segregation



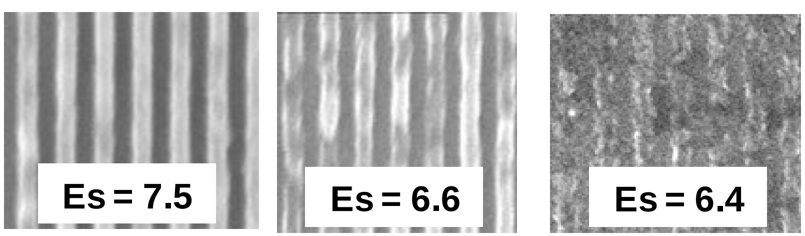
Thick Films Thin Films

Fluorinated PAGs are know to segregate to resist surfaces.

This stratification can cause surface inhibition, and flatter resist tops. (Less top-loss)

Film Thickness

120 nm 60 nm 30 nm

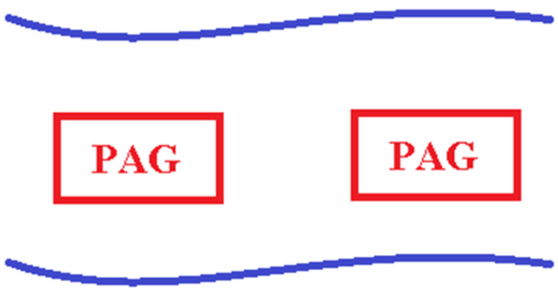


Could changes in the concentration of PAG at the surface be responsible for poorer imaging in thin films?

Exploration of Three JSR Resists:

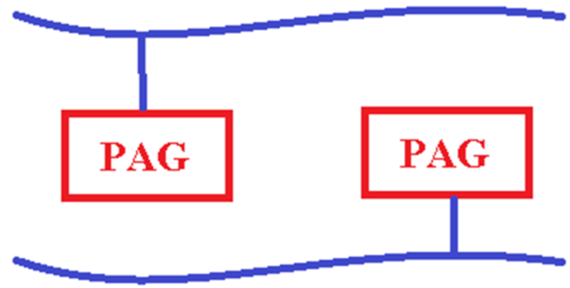
Resists Provided by JSR:

Resist A (Blend):



Higher PAG Diffusion

Resist B (Bound):



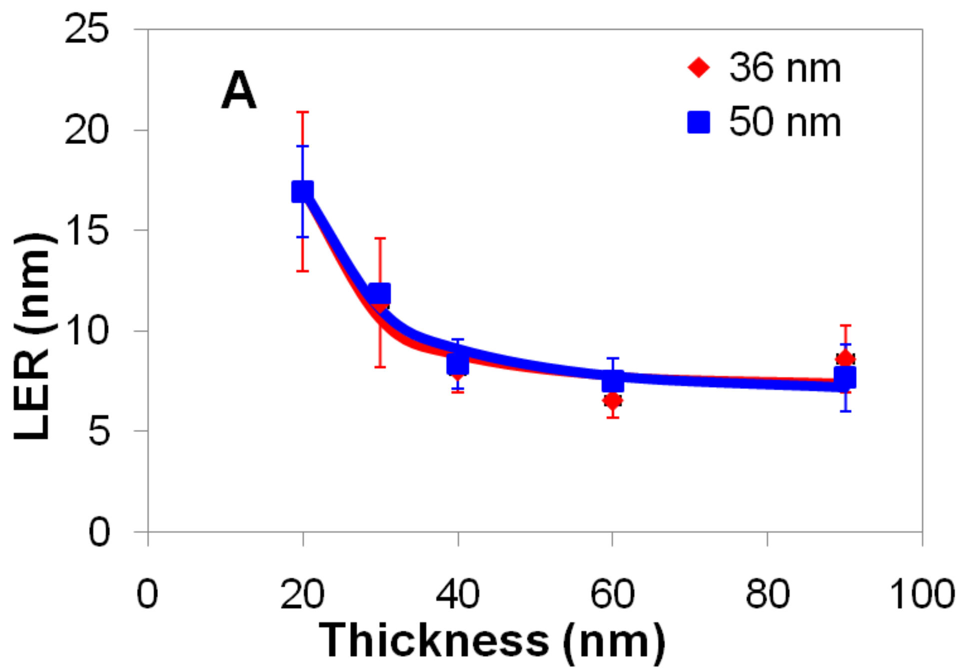
Lower PAG Diffusion

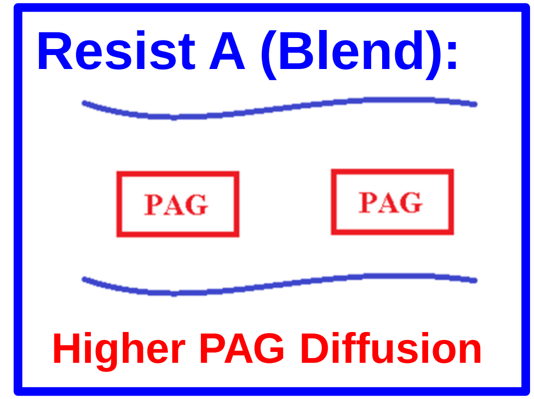
Resists A and B have a comparable polymer.

Resist C (Blend):

Baseline Litho

Resist A: PAG *Blend* Resist

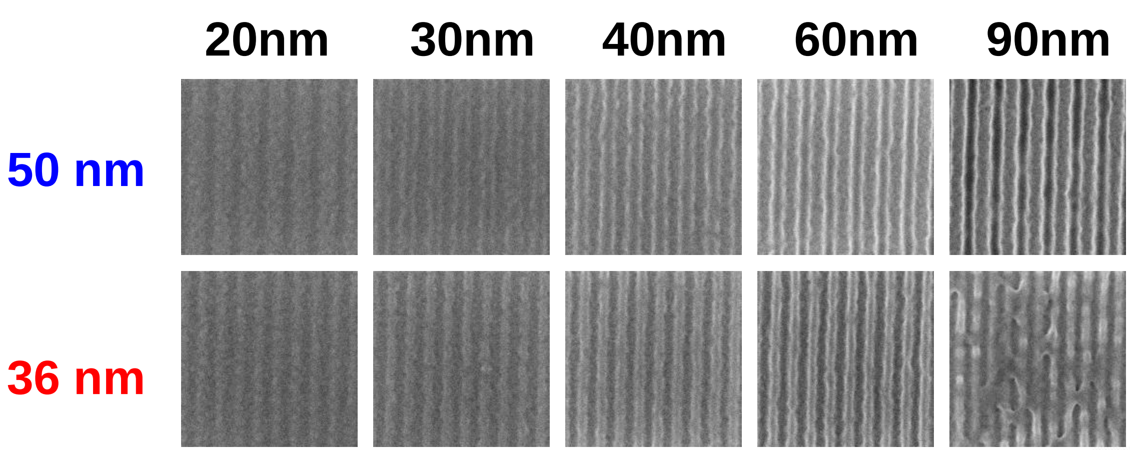




CNSE Model:

$$LER(d) = LER_\infty\left[1+\left(\frac{A'}{d}\right)^{\delta'}\right]$$

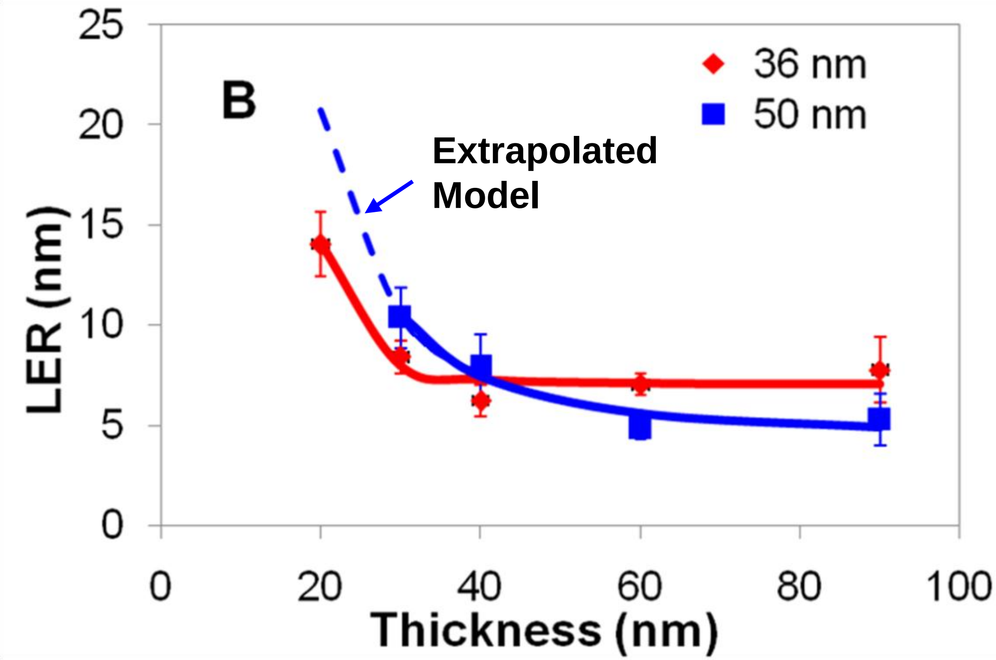
Avg φ: 128 nm^2

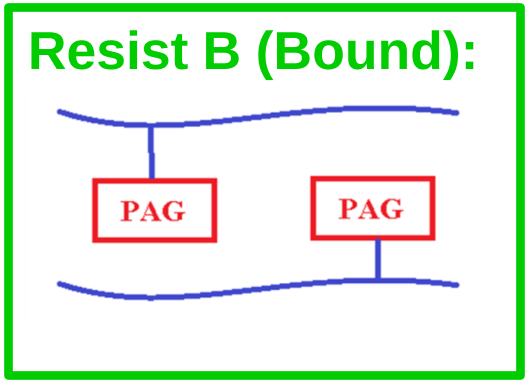


φ_{50} = 149 nm^2

φ_{36} = 107 nm^2

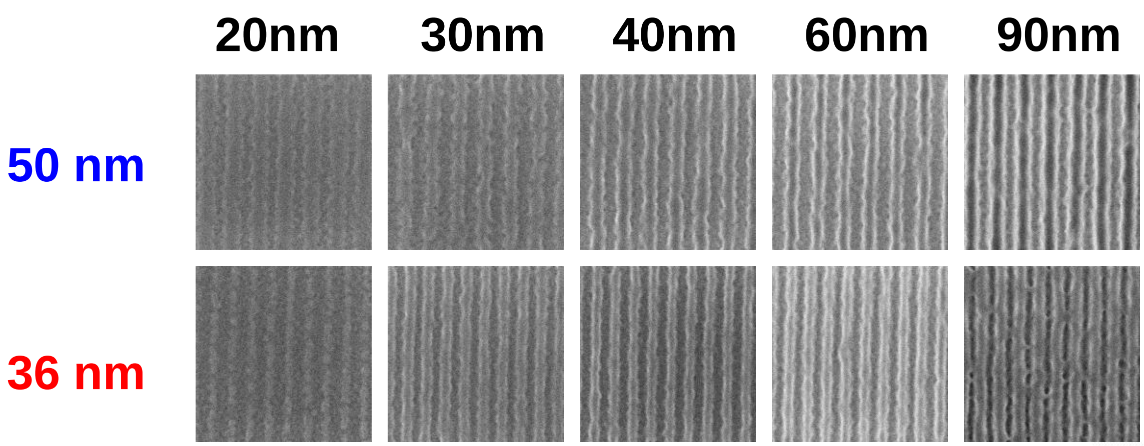
Resist B: PAG *Bound* Resist





Avg φ: 134 nm^2

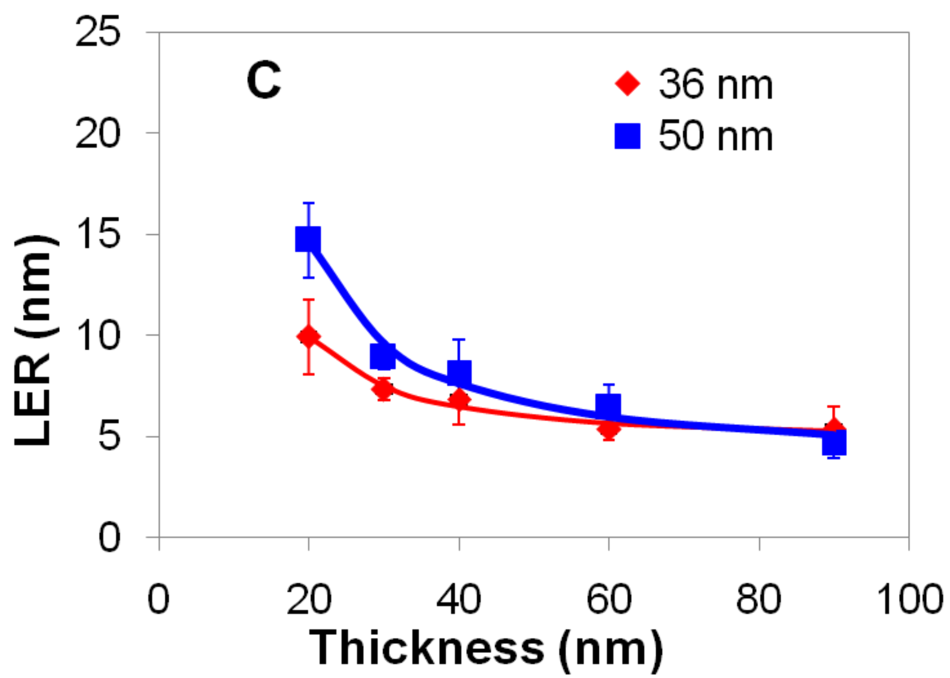
* 50 nm h/p data at 20 nm thickness was not resolved. Model is fit off of the remaining four points.



φ_{50} = 201* nm^2

φ_{36} = 66 nm^2

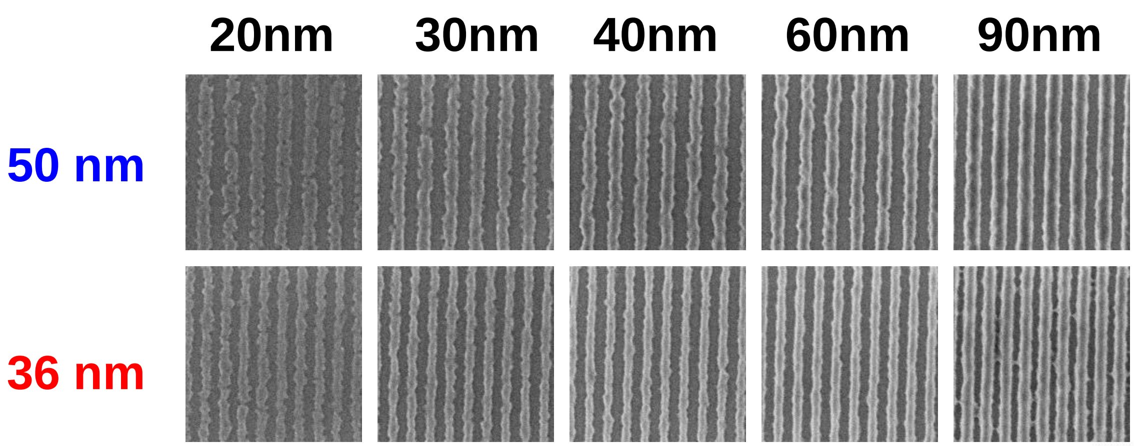
Resist C: Baseline Resist



Resist C (Blend):

Baseline Litho

Avg φ: 155 nm²



φ_{50} = 209 nm²

φ_{36} = 101 nm²

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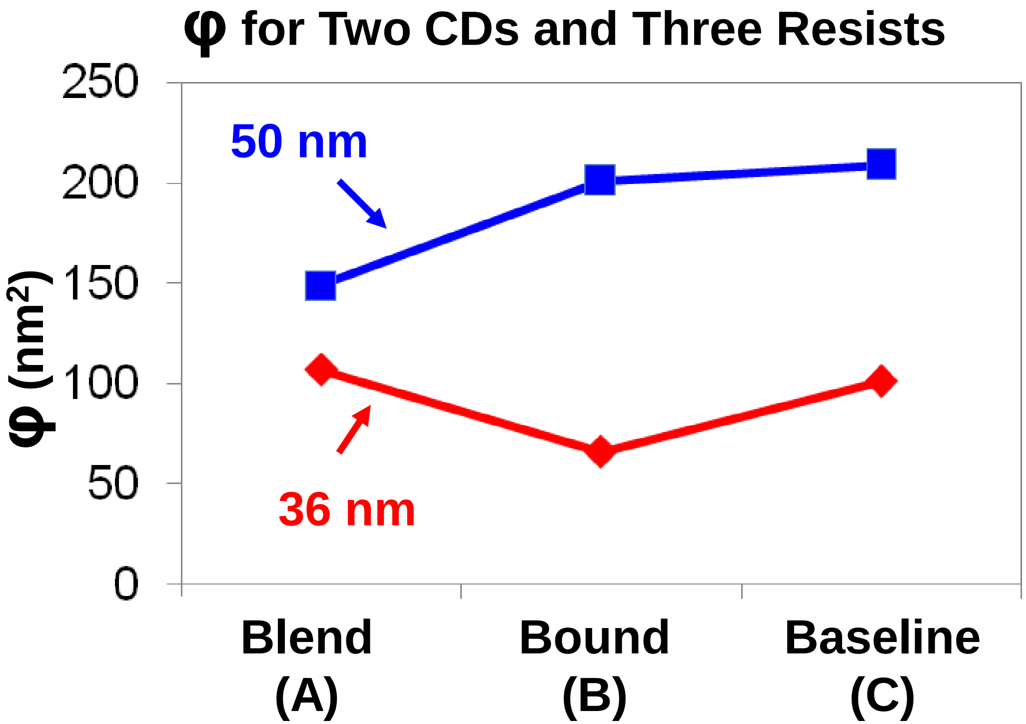
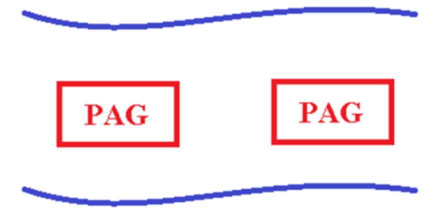
Exploration of Three JSR Resists:



Higher φ: Worse LER thickness dependence.

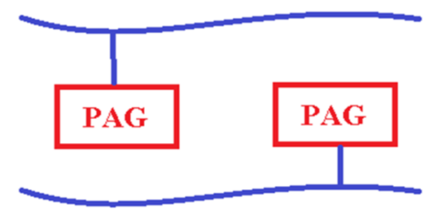
Bound PAGs have better φ for 36-nm lines and worse φ for 50-nm lines.

Resist A (Blend):



Higher PAG Diffusion

Resist B (Bound):



Lower PAG Diffusion

Resist C (Blend):

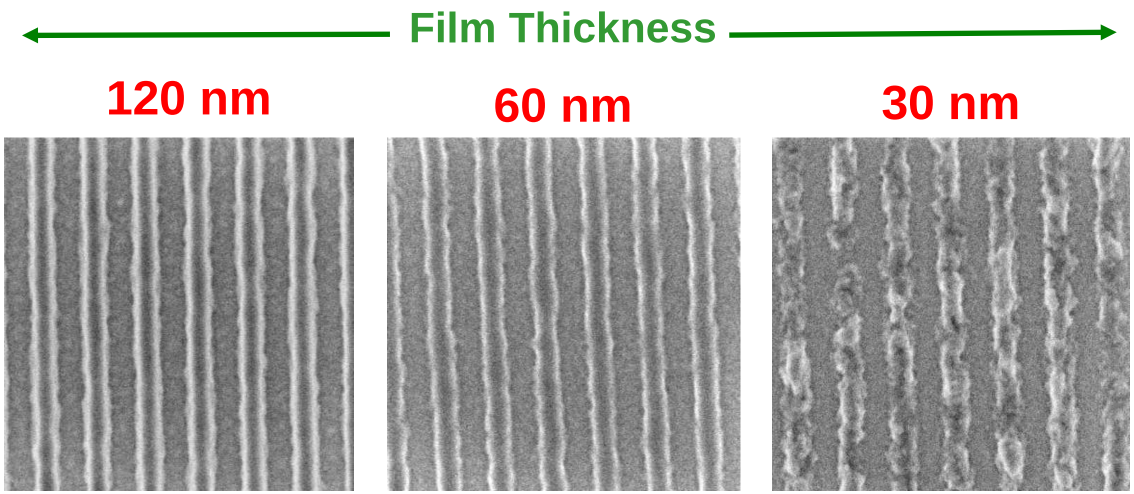
Baseline Litho

LER Limits of Resist Thin Films

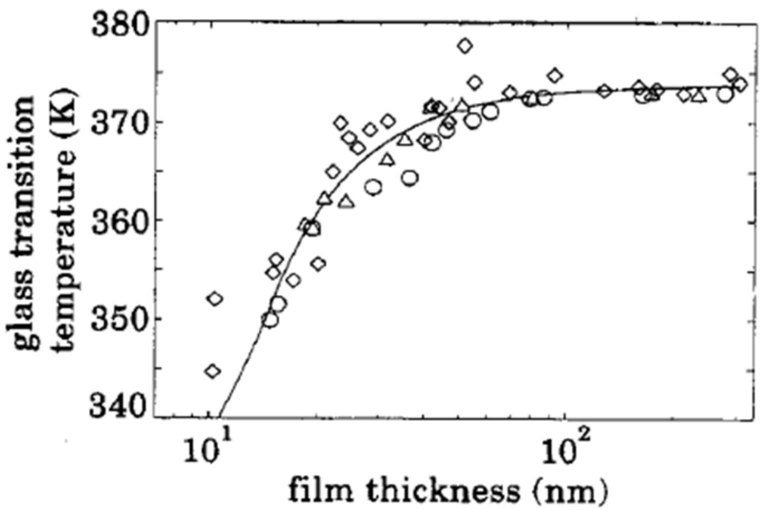
Determine the root cause of the degradation of LER vs. thickness in EUV resists by studying this phenomenon as a function of resist:

- **PAG Segregation - Today**
- **Glass Transition Temperature (Tg) - Today**
- **Substrate Interaction - SPIE**
- **Optical Density - SPIE**

III. Glass-Transition Temperature



Tops of resist profiles are very different in thin films



Tg Changes Dramatically at thin films.

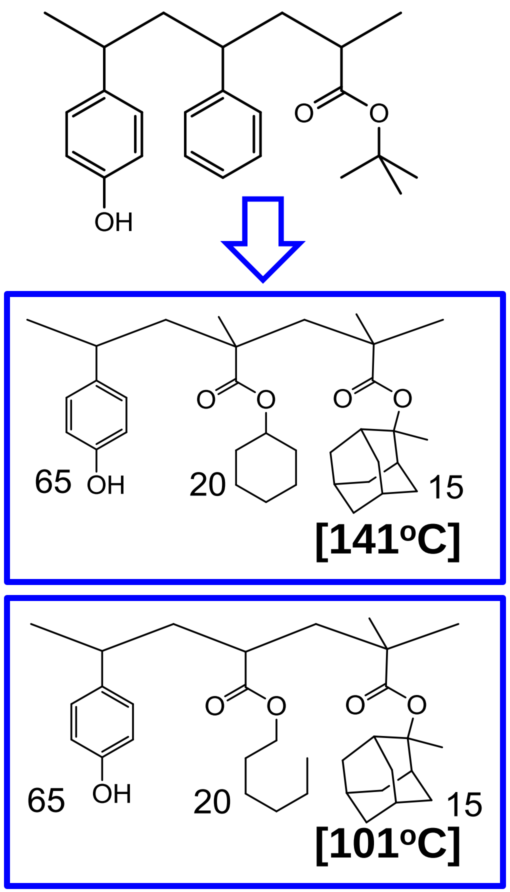
Are Tg and LER effects connected?

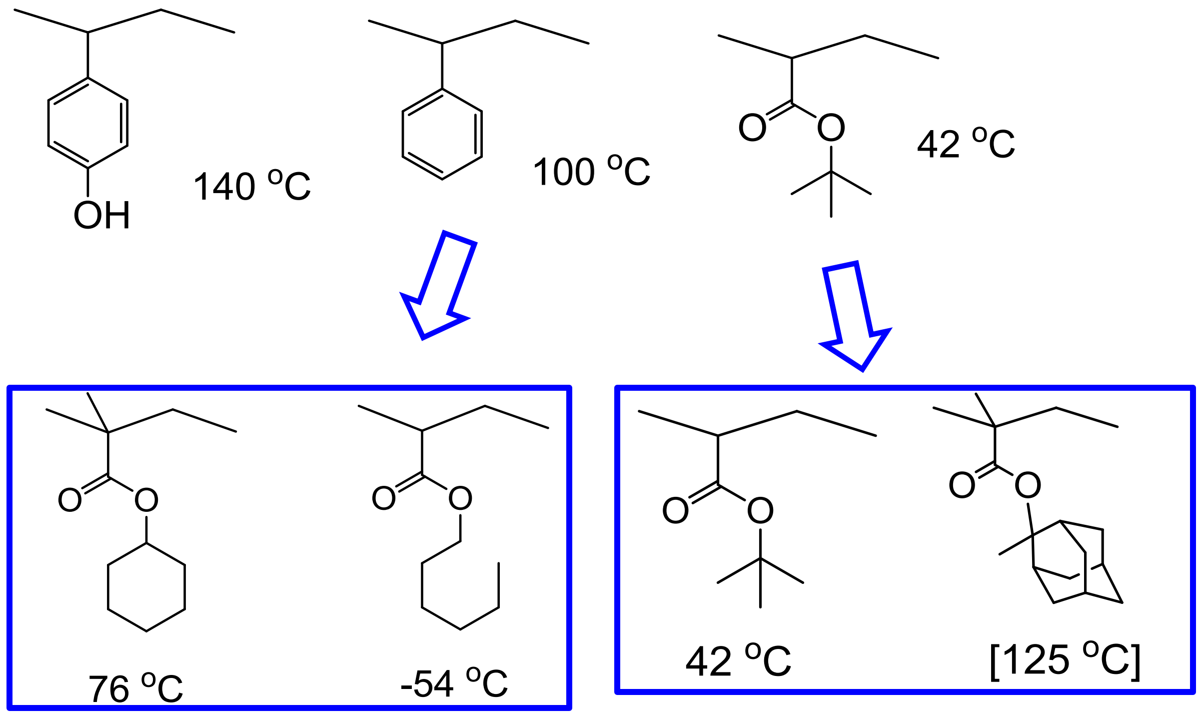
Keddie et al., Europhysics Letters, 27(1), pp. 59-64, 1994.

Systematic Study of Polymer Tg on LER/Thickness Problem

Prepare high & low Tg polymers and determine:

- **LER *vs.* thickness.**
- **Acid-diffusion length (EL) *vs.* thickness**





* Tg values in brackets are modeled results. Bicerano, "Prediction of polymer properties" / Fox Tg

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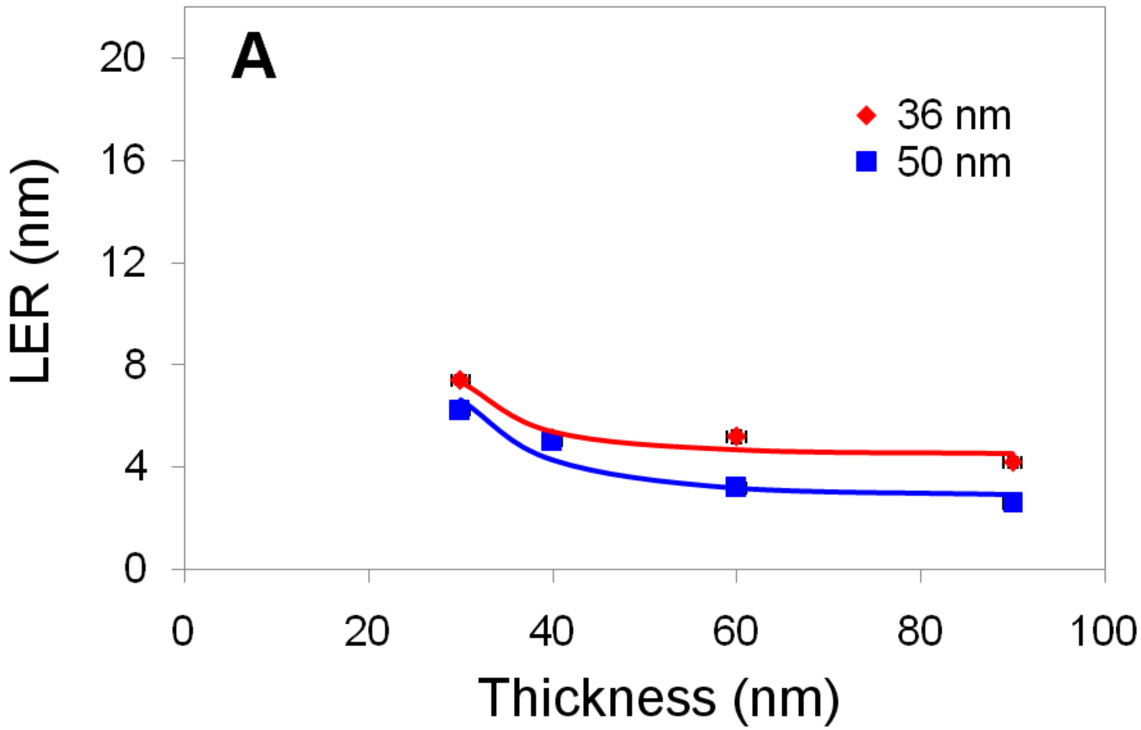
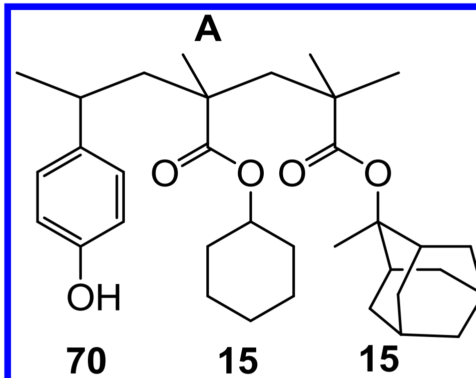
Polymer A



PAB: 130 °C / 60 s

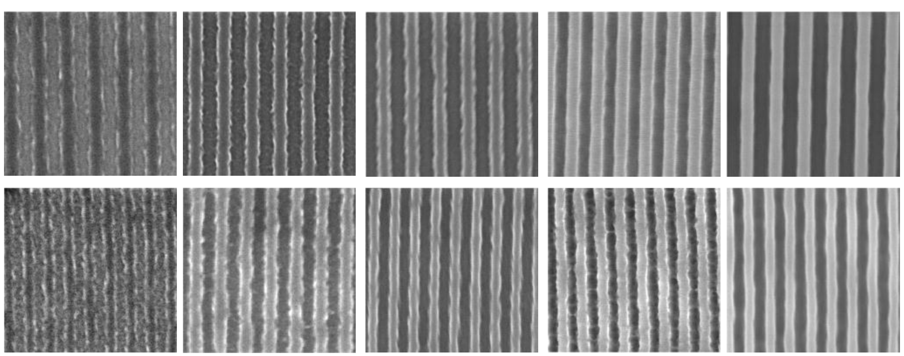
PEB: 110 °C / 90 s

$T_{g\,\infty}$ = 162 °C



50 nm

36 nm



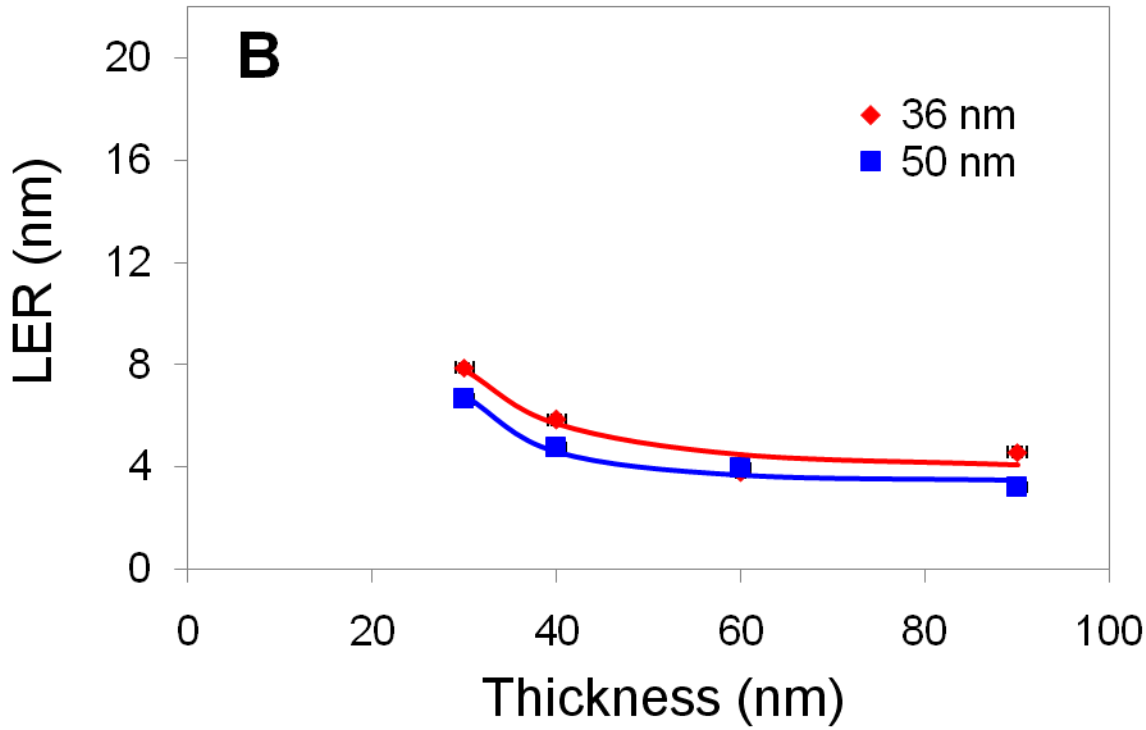
20 30 40 60 90

Film Thickness (nm)

φ_{50} = 46 nm²

φ_{36} = 27 nm²

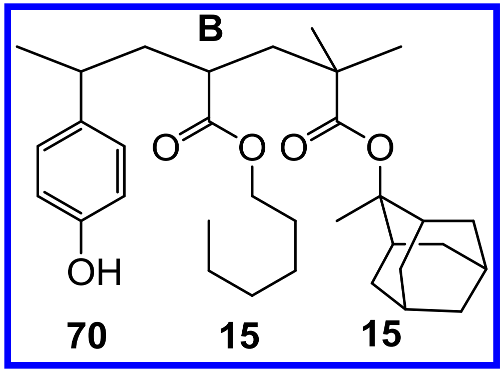
Polymer B



PAB: 130 ºC / 60 s

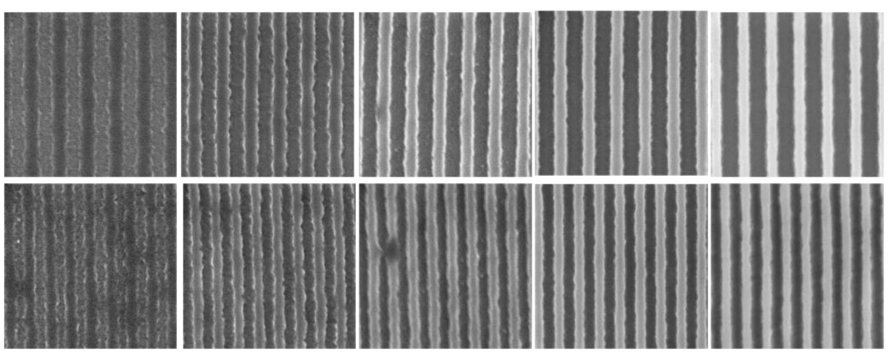
PEB: 110 ºC / 90 s

$T_{g\,\infty}$ = 157 ºC



50 nm

36 nm



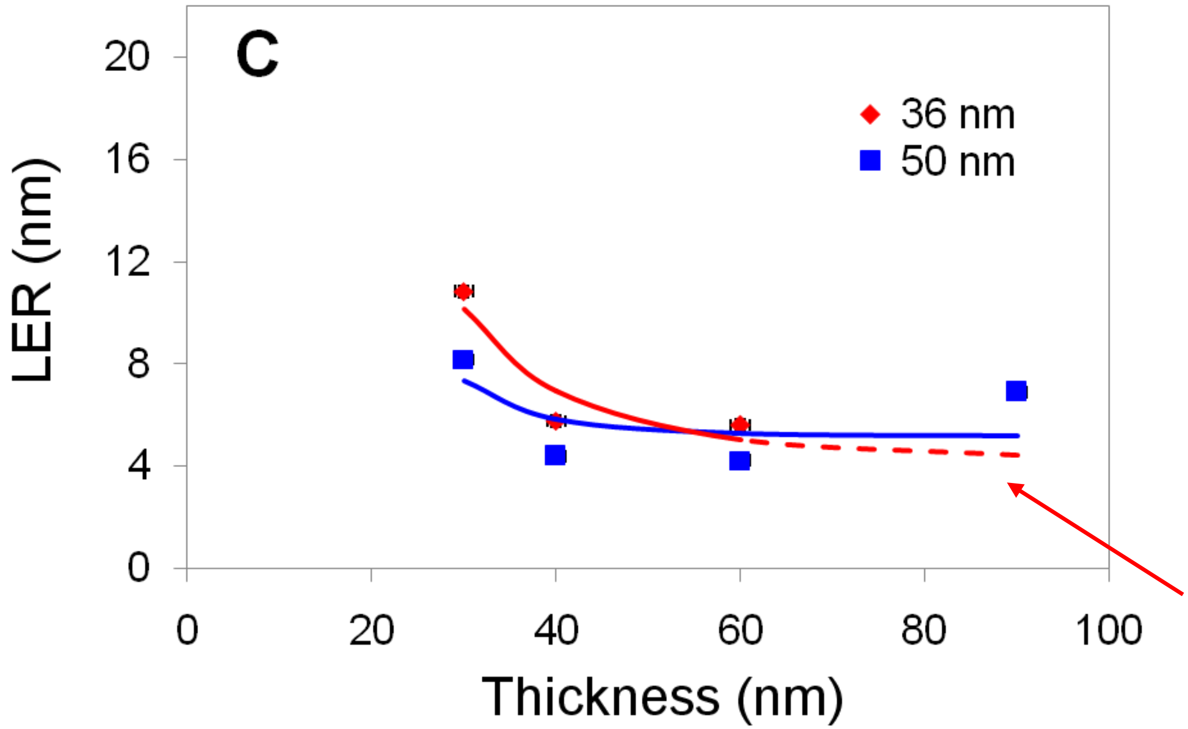
20 30 40 60 90

Film Thickness (nm)

φ_{50} = 36 nm^2

φ_{36} = 59 nm^2

Polymer C

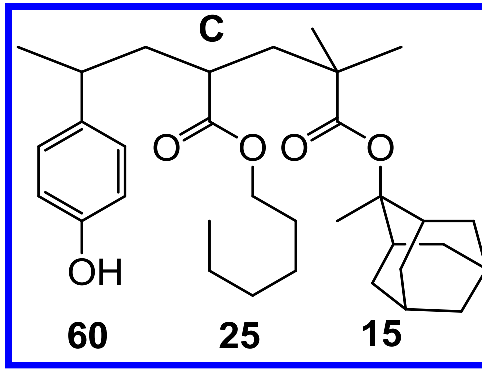


Extrapolated Model

PAB: 130 °C / 60 s

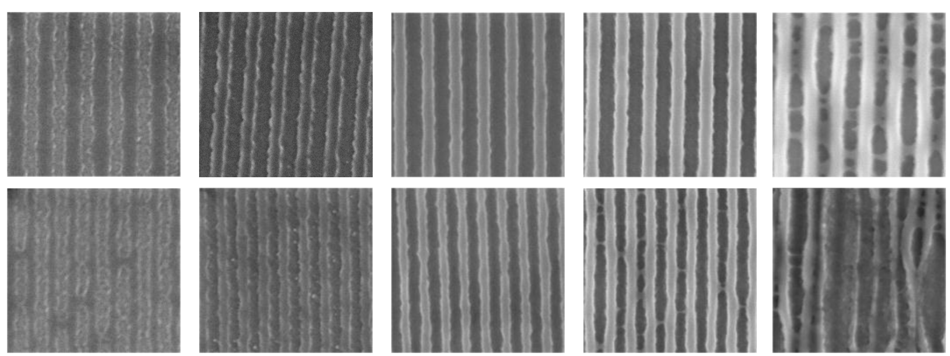
PEB: 110 °C / 90 s

$T_{g\,\infty}$ = 130 °C



50 nm

36 nm



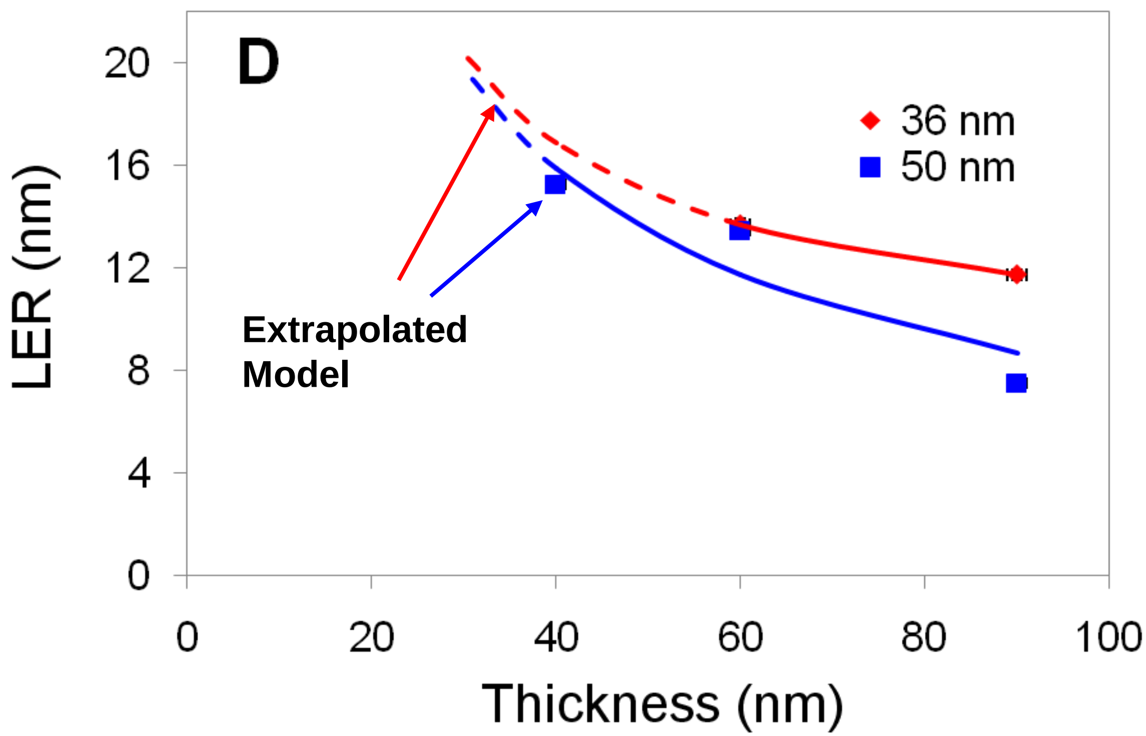
20 30 40 60 90

Film Thickness (nm)

$\varphi_{50} = 20\ nm^2$

$\varphi_{36} = 93\ nm^2$

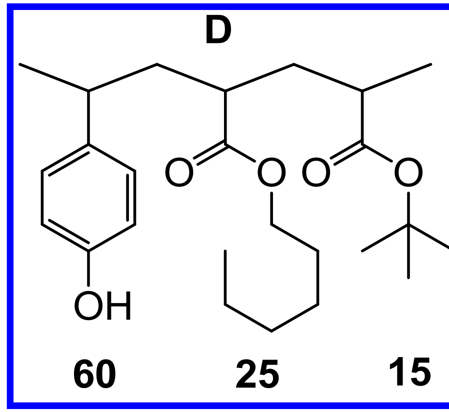
Polymer D



PAB: 130 ^{o}C / 60 s

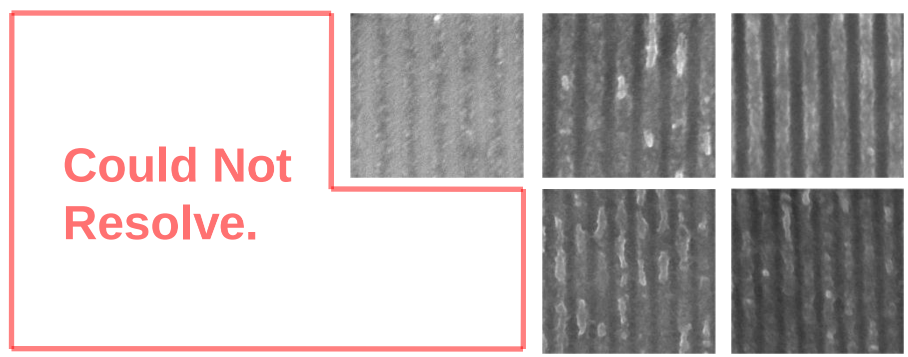
PEB: 110 ^{o}C / 90 s

$T_{g\,\infty}$ = 106 ^{o}C



50 nm

36 nm



20 30 40 60 90

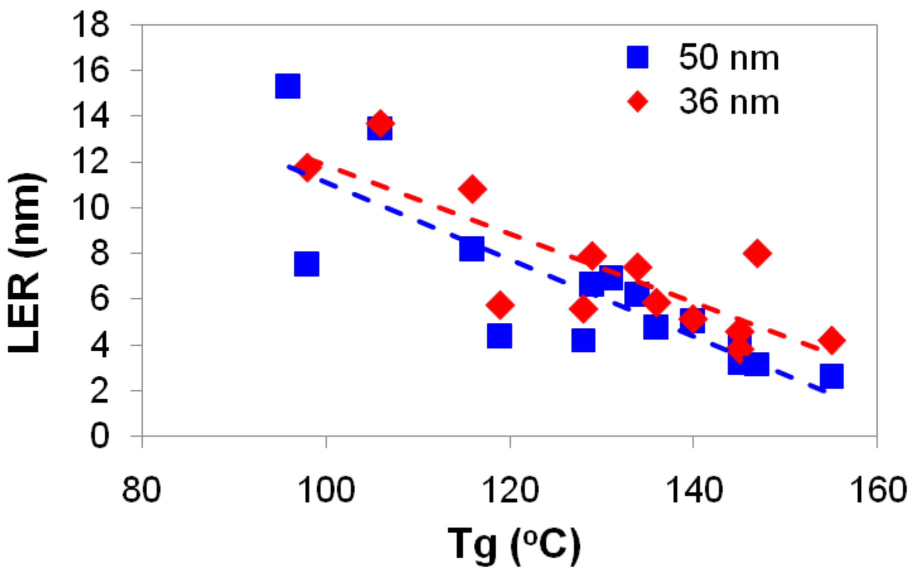
Film Thickness (nm)

φ_{50} = 743 nm^{2}

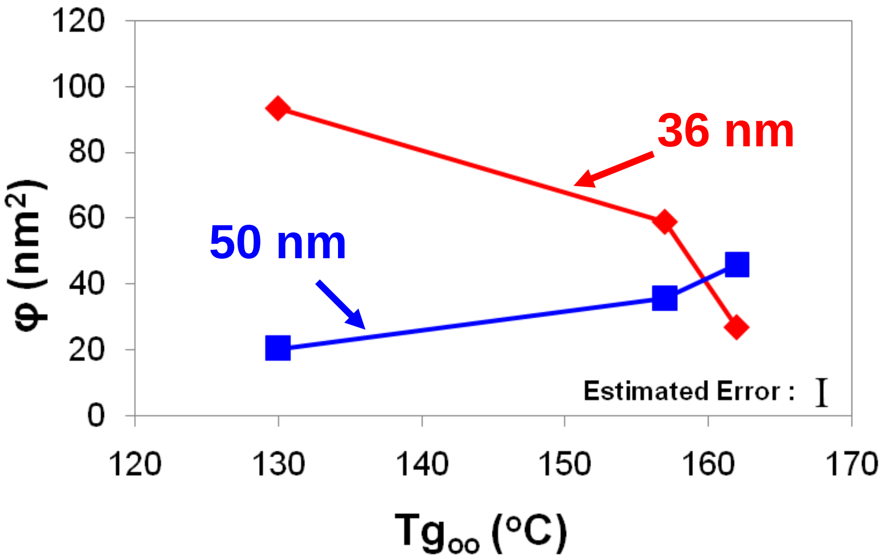
φ_{36} = 349 nm^{2}

Comparison of Tg Results

LER vs. Film Tg for all Thicknesses



φ as a function of Tg



- In general, LER gets worse at higher Tg.
- Since Tg is a function of thickness, this may partially explain LER degradation.
- As Tg in increases, the φ for 36-nm lines improves while the φ for 50 nm lines gets worse.

Summary and Future Directions

PAG Segregation:

- A mathematical model was developed to quantify the dependence of film thickness on LER (**φ**).
- This model was applied to three JSR resists; two of which directly compare PAG mobility in a film.
- In particular, **φ,** is better for small CDs (36 nm half-pitch).

Glass Transition Temperature:

- A series of polymers were designed with similar lithographic properties but varying glass transition temperatures.
- Here, **φ** improves with increasing Tg for 36-nm lines, but gets worse for 50-nm lines.
- These results point towards a possible acid diffusion mechanism. More investigation is needed.

Optical Density and Substrate Interaction:

- We are currently evaluating the effect of optical density and substrate interaction on LER through film thickness.

Acknowledgements

Group Members Past and Present:

Craig Higgins

Seth Kruger

Srividya Revuru

Staff at EMET

Staff at BMET

King Industries

Dow Chemical

Project Funding By:

SEMATECH

Accelerating the next technology revolution.

Ellipsometry Help:

Alain Diebold

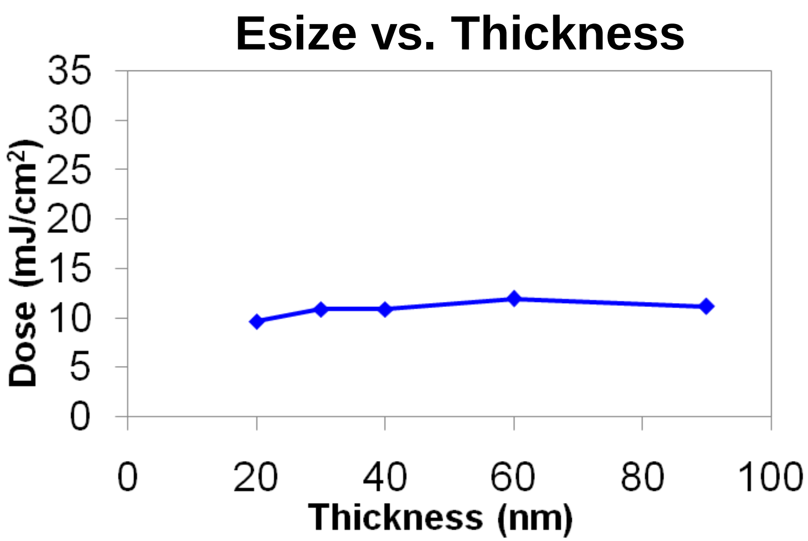
And you for your time…

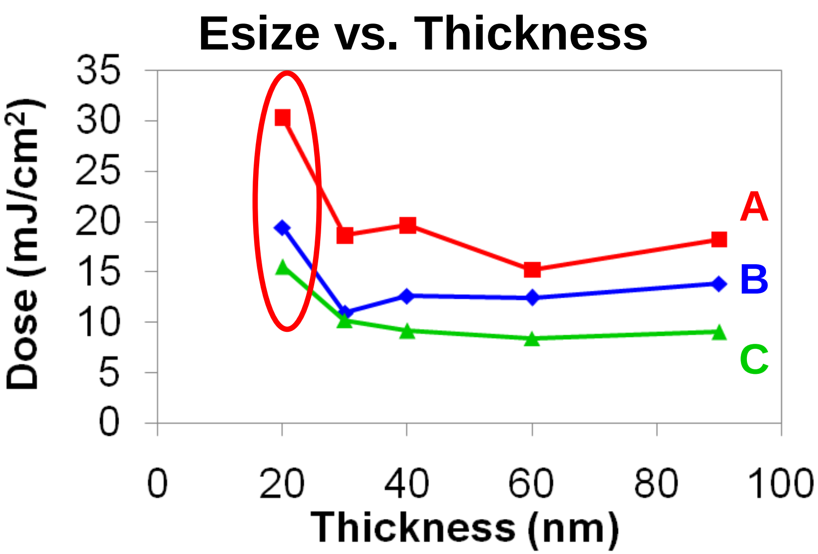
Appendix

Resists Coated to 20-nm Showed Unusual Behavior on Silicon

PAG Segregation:
- Albany EMET
- NCX011 Underlayer
- JSR Resists

Glass Transition Temperature:
- Berkeley BMET
- Primed Silicon
- CNSE Resists

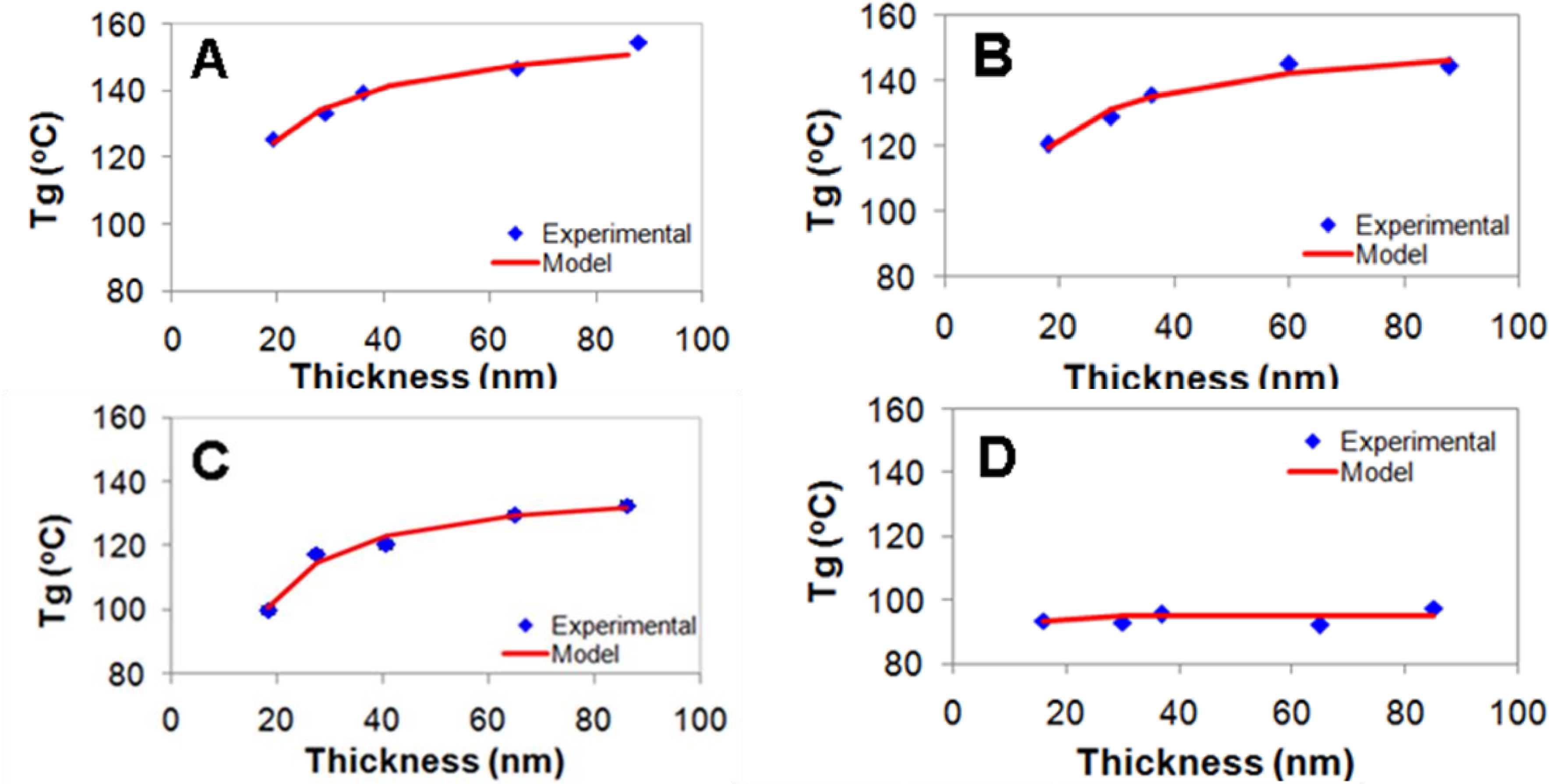




These 20-nm results were omitted from the Tg study.

Further investigation into this peculiarity is planned.

Tg vs. Film Thickness



Polymer	Tg $_\infty$	φ_{Tg} (nm · °C)
A	162	1266
B	157	1235
C	130	884
D	106	528

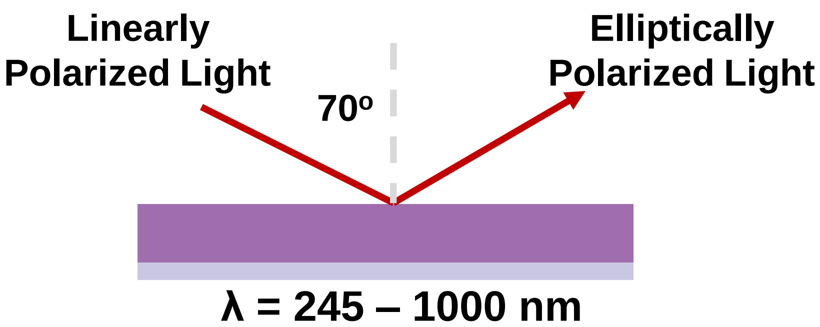
Keddie Equation:[1]

$$T_g(d) = T_{g\,\infty}\left[1 - \left(\frac{A}{d}\right)^{\delta}\right]$$

1. Keddie et al., Europhysics Letters, 27(1), pp. 59-64, 1994.

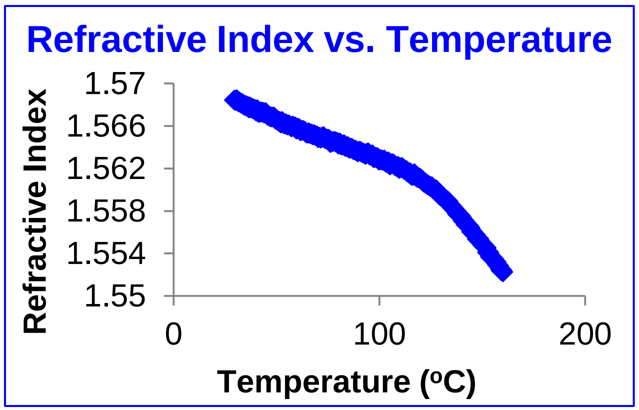
Measurement of Tg in Polymer Films

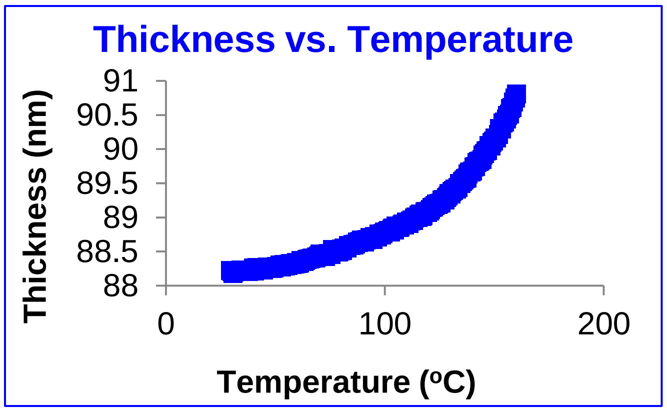
Basic Ellipsometry:



Direct Measurement of psi (ψ) and del (Δ) → **Model** → **Indirect Measurement of Thickness (d) and Refractive Index (n)**

Glass Transition (Tg): Temperature at which a polymer can overcome cohesive energy.



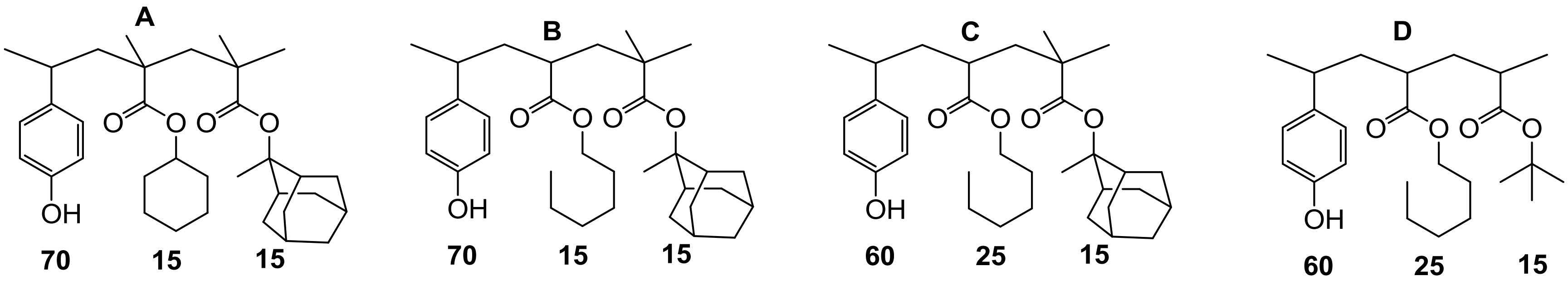


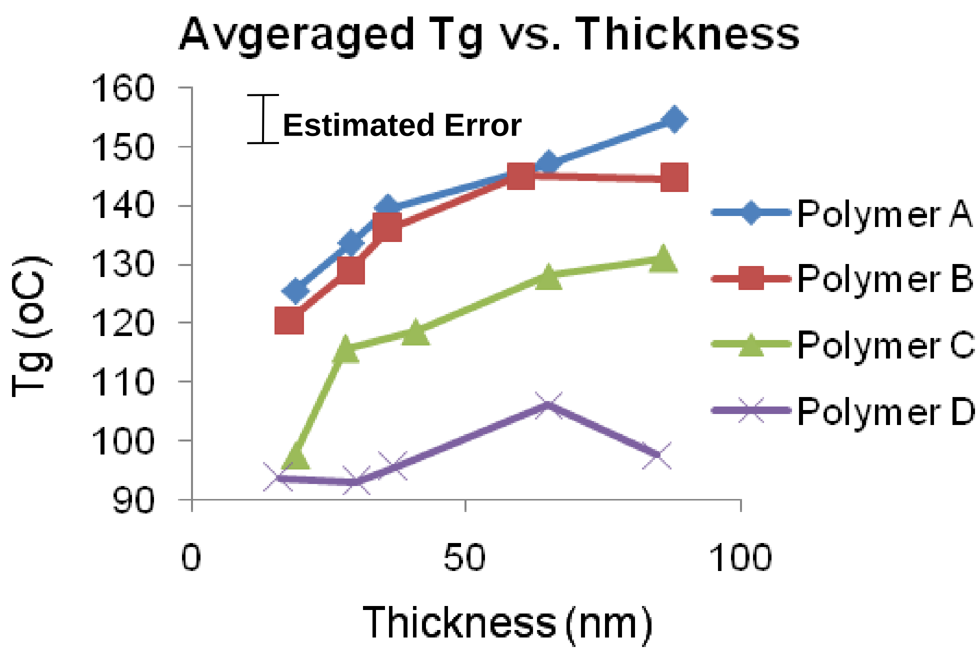
$$h(T) = w\left(\frac{M-G}{2}\right) ln\left[cosh\left(\frac{T-T_g}{w}\right)\right] + (T-T_g)\left(\frac{M+G}{2}\right) + c \quad (1)$$

Films were heated from 25 to 160 ºC for 20 mins to outgas residual solvent. Measurements were then taken on cooling from 160 to 25 ºC for 20 mins and data fitted to Dalnoki-Veress eq.

1. Dalnoki-Veress et al., Physical Review E 63 031801

Polymer Set Design for Initial Exposure Studies



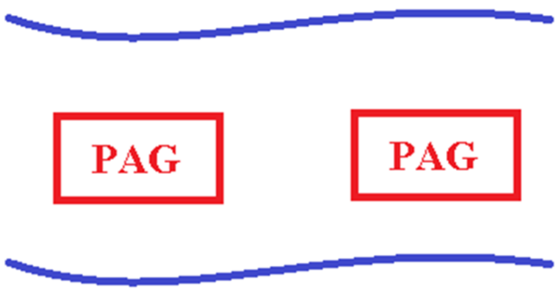


* Tg values averaged between thickness and refractive index curves

PAG Segregation Summary

Resists Provided by JSR:

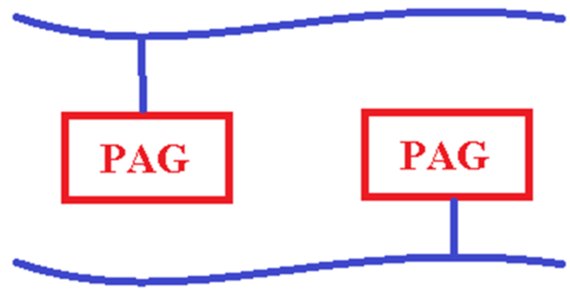
Resist A (Blend):



Higher PAG Diffusion

Avg φ: 128 nm^2

Resist B (Bound):



Lower PAG Diffusion

Avg φ: 134 nm^2

Resist C (Blend):

Baseline Litho

Avg φ: 155 nm^2

Brian:
Not Ave.

The resists tested seem to have different results depending on CD.